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Indian Standard

GUIDANCE FOR ENVIRONMENTAL TESTING

PART II COLD AND DRY HEAT TESTS

(First Reprint AUGUST 1996)

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 9 *July* 1978

Indian Standard

GUIDANCE FOR ENVIRONMENTAL TESTING

PART II COLD AND DRY HEAT TESTS

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GUIDANCE FOR ENVIRONMENTAL TESTING

PART II COLD AND DRY HEAT TESTS

0. FOREWORD

0.1 This Indian Standard (Part II) was adopted by the Indian Standards Institution on 26 December 1977, after the draft finalized by the Environmental Testing Procedures Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

0.2 This standard has been largely based on IEC Publication 68-3-1 (1974) ' Basic environmental testing procedures, Part 3 : Background information, Section One : Cold and dry heat tests ' issued by the International Electrotechnical Commission.

0.3 This standard should be read in conjunction with IS : 9000 (Part II)-1977* and IS : 9000 (Part III)-1977†.

0.4 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960‡. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard (Part II) provides guidance for cold and dry heat tests intended for electronic and electrical items, and other items employing similar techniques.

2. TERMINOLOGY

2.1 For the purpose of this standard, the definitions and explanation of terms given in IS : 9000 (Part I)-1977§ shall apply.

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*Basic environmental testing procedures for electronic and electrical items: Part II Cold test.

†Basic environmental testing procedures for electronic and electrical items: Part III Dry heat test.

‡Rules for rounding off numerical values (*revised*).

§Basic environmental testing procedures for electronic and electrical items: Part I General.

3. GENERAL

3.1 Introduction

3.1.1 The performance of components and equipment is influenced and limited by their internal temperatures which depend on the external ambient conditions and on the heat generated within the device itself. Whenever temperature gradients exist in the system formed by a device and its surroundings, a process of heat transfer will ensue.

3.1.2 The tests, meant to study these, cover cold and dry heat testing, with both sudden and gradual change of the temperature, and of non-heat dissipating and heat dissipating items (the latter with or without artificial cooling).

3.1.3 The use of test chambers with and without forced air circulation is covered as appropriate. A general block diagram of the total procedure is given in Fig. 1.

3.2 Reference Ambient Conditions — Unfortunately, the actual ambient conditions in which the device will have to work are normally neither accurately known nor well defined, so that it is not possible to use them as a basis for design, specification or testing. For these purposes, it is necessary to define conventional reference ambient conditions which may be specified taking into account the considerations covered in **3.3** to **3.6**.

3.3 Devices Without Heat Dissipation — If the ambient temperature is uniform and constant and there is no generation of heat within the device, heat will flow from the ambient atmosphere into the device if the former is at a higher temperature, and from the device into the ambient atmosphere if the latter is at a lower temperature. This heat transfer will continue until the device has reached in all its parts the temperature of the surrounding atmosphere. From that moment on, the heat transfer ceases and will not start again unless the ambient temperature changes. In this case, the definition of a reference ambient temperature is simple, the only condition being that it shall be uniformly distributed and constant. For the case when the device does not reach the temperature of the surrounding atmosphere, the definition of a reference temperature is more complicated and the conclusions in **3.4** apply.

3.4 Devices with Heat Dissipation

3.4.1 If heat were generated within the device and there were no heat transfer to the ambient atmosphere, the temperature of the device would rise beyond any limit. It follows that if an ultimate steady temperature is reached, this implies that heat is flowing continuously from the device into the atmosphere whereby the device is always cooled, no matter what the ambient atmosphere is. Only if the ambient temperature rises, a further rise of temperature within the device may occur.

3.4.2 The reference ambient temperature for this case shall obviously be so defined that simple and well reproducible conditions for heat transfer are obtained. Because heat transfer is accomplished by means of three distinct mechanisms, namely, convection, radiation and conduction, well-defined conditions for each of them shall be obtained separately but simultaneously.

3.4.3 If more than one item is subjected to one of the dry heat tests in the same chamber, it is necessary to ensure that all items are in the same ambient temperature and have identical mounting conditions. It has not, however, been found necessary to differentiate between testing of single items and multiple items when the cold test is being performed.

3.5 Ambient Temperature

3.5.1 Users of components and equipment, particularly equipment, require to know the maximum and minimum values of ambient temperature between which the item will operate and these should be specific for the purpose of testing.

3.5.2 Certain difficulties arise due to the fact that heat transfer is connected with temperature gradients and that therefore the temperature of the medium surrounding the device is necessarily varying in space. Consequently, the 'ambient temperature' of the surrounding atmosphere shall be specially defined.

3.6 Surface Temperatures — Considering that the principal influence on the performance of the device is its own temperature, for the purposes of monitoring and adjusting test gear, it may be convenient to refer to the temperatures at some significant points on the surface or even in the interior of the item.

4. MECHANISMS OF HEAT TRANSFER

4.0 The three basic mechanisms of heat transfer, namely, convection, radiation and conduction, while subjecting the items to dry heat and cold tests, and the reasons for the differing test procedures (*see* Fig. 1), are described below.

4.1 Thermal Convection

4.1.1 Heat transfer through thermal convection is a very important part of heat transfer from heat dissipating items exposed to test chamber conditions.

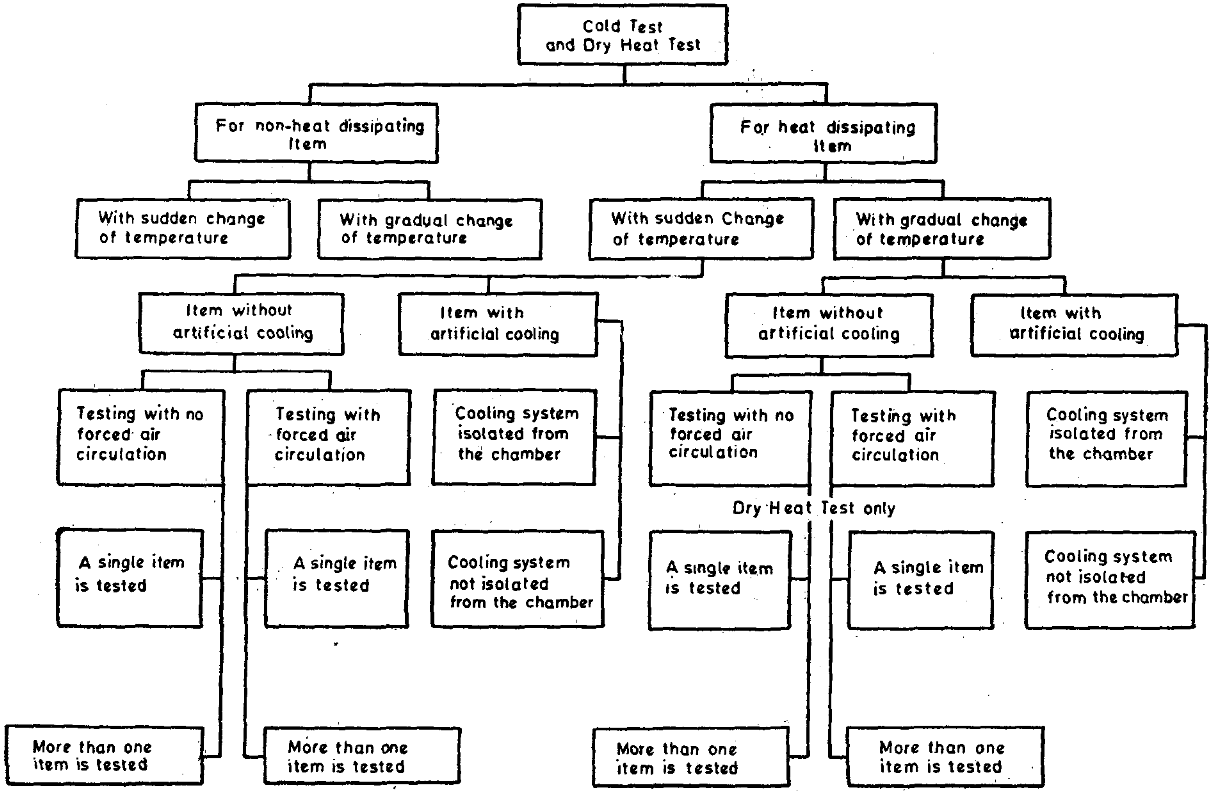

Cold Test and Dry Heat Test
For non-heat dissipating Item
For heat dissipating Item
With sudden change of temperature
With gradual change of temperature
With sudden Change of temperature
With gradual change of temperature
Item without artificial cooling
Item with artificial cooling
Item without artificial cooling
Item with artificial cooling
Testing with no forced air circulation
Testing with forced air circulation
Cooling system isolated from the chamber
Testing with no forced air circulation
Testing with forced air circulation
Cooling system isolated from the chamber
Dry Heat Test only
A single item is tested
A single item is tested
Cooling system not isolated from the chamber
A single item is tested
A single item is tested
Cooling system not isolated from the chamber
More than one item is tested
More than one item is tested
More than one item is tested
More than one item is tested

FIG. 1 GENERAL BLOCK DIAGRAM, COLD AND DRY HEAT TESTS

The coefficient of heat transfer from the surface of the test item to the ambient air is affected by the velocity of the surrounding air. The heat transfer is more efficient the higher the air velocity. Therefore, with the same temperature of the ambient air, the surface temperature of the test item will be lower the higher the air velocity. This effect is illustrated in Fig. 2 and 3.

In addition to the influence on the surface temperature of the test item at any one location, the airflow will also effect the temperature distribution on the surface of the test item. This effect is illustrated in Fig. 4.

4.1.2 It is evident from Appendix A that there is no simple relationship between surface temperature and distribution for different air velocities and airflow directions. It is also obvious that if in conformance with actual conditions, testing were to be defined with a particular value of air velocity and airflow direction, this would involve problems in the design of chambers.

The necessity for a well-defined, reproducible test condition where the test results can be easily compared with actual conditions leads to the use of ' free air conditions '.

4.1.3 ' Free air conditions ' means conditions within an infinite space where the movement of the air is effected only by the heat dissipating item itself, and the energy radiated by the item is absorbed. It is not practical for testing purposes to try to reproduce free air conditions (*see* **5**).

It is shown in Appendix B that the use of free air conditions as a reference does not normally lead to expensive or impracticably large testing chambers. Since free air conditions have certain technical advantages and are normally easier to comply with than specified forced air conditions, they are used as the preferred way of performing cold and dry heat tests on heat dissipating items.

Due to reasons given in **5**, there are cases where difficulties arise in testing with no forced air circulation.

Two alternative methods, where forced air circulation with low air velocity is allowed, have therefore been given. The first method applies to the cases where the size of the chamber is large enough to comply with the requirements in Appendix B, but where the heating or cooling of the chamber requires forced air circulation.

The second method applies to the cases where the chamber is too small to comply with the requirements of Appendix B, or where the first method cannot be used for other reasons.

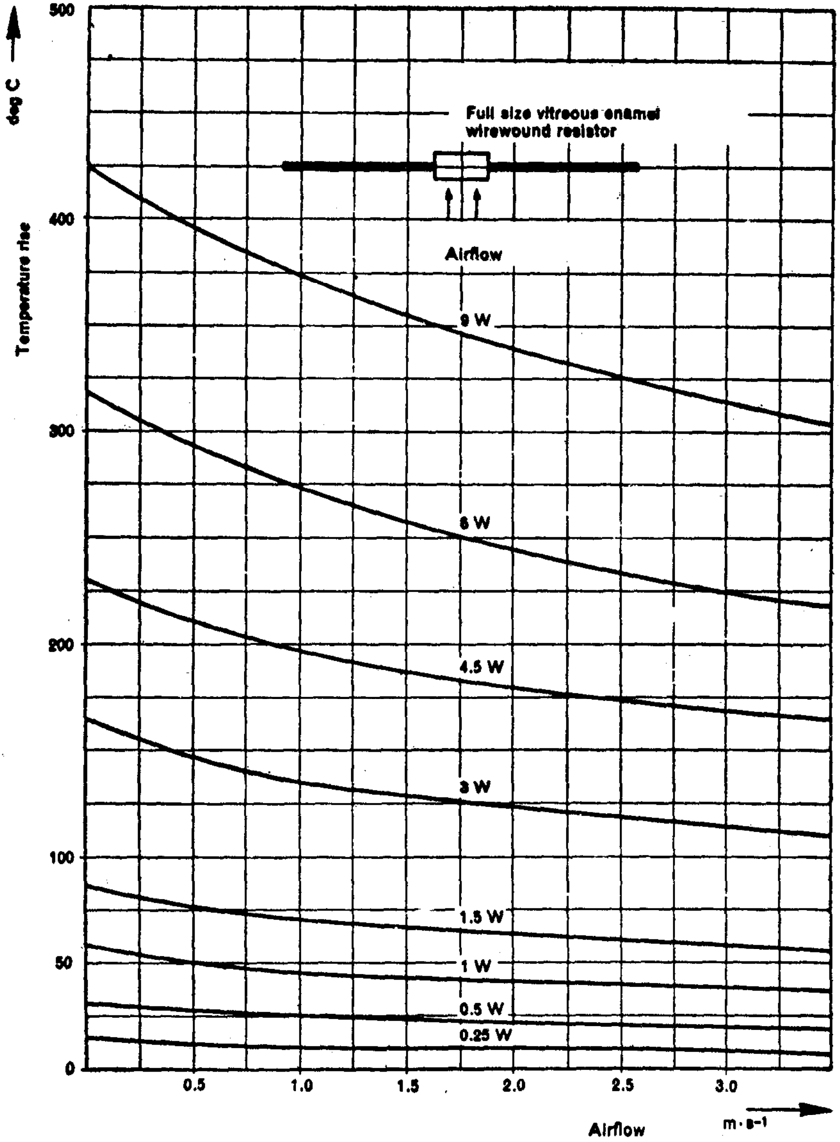


FIG. 2 EXPERIMENTAL DATA ON THE EFFECT OF AIRFLOW ON SURFACE TEMPERATURE OF A WIREWOUND RESISTOR — RADIAL AIRFLOW

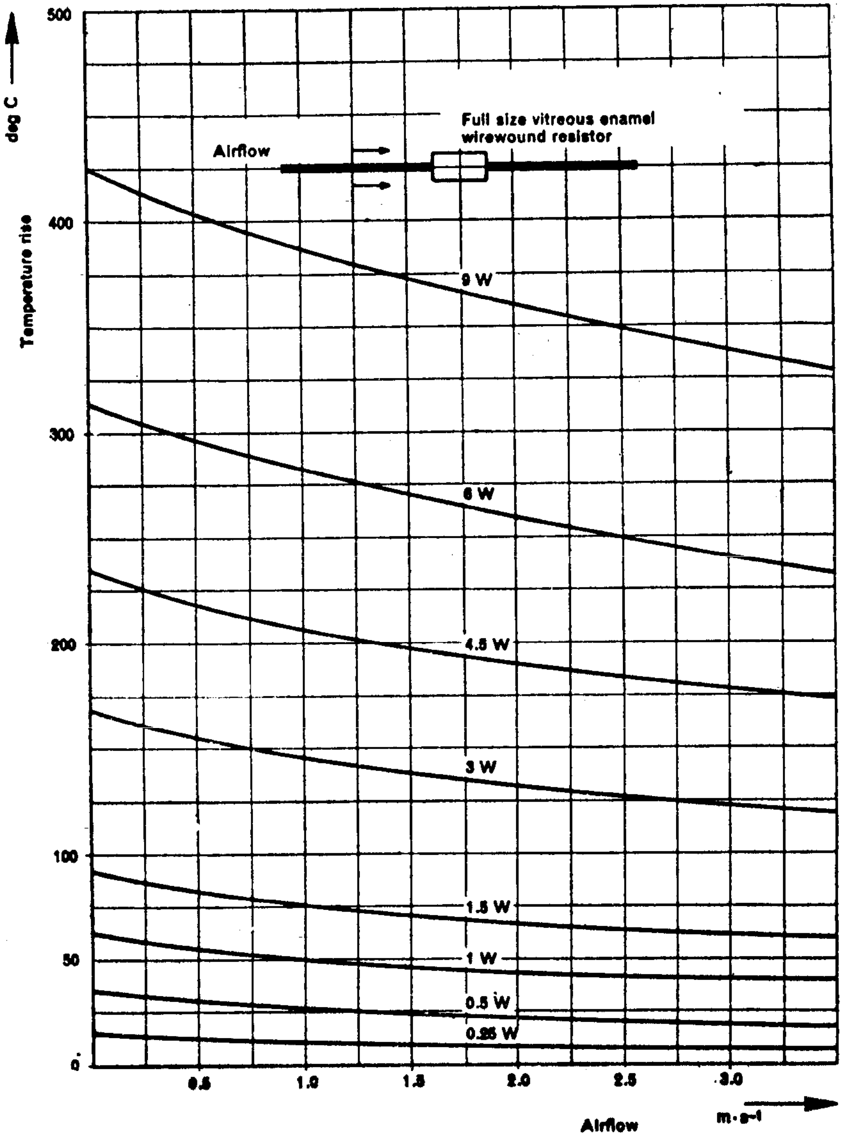
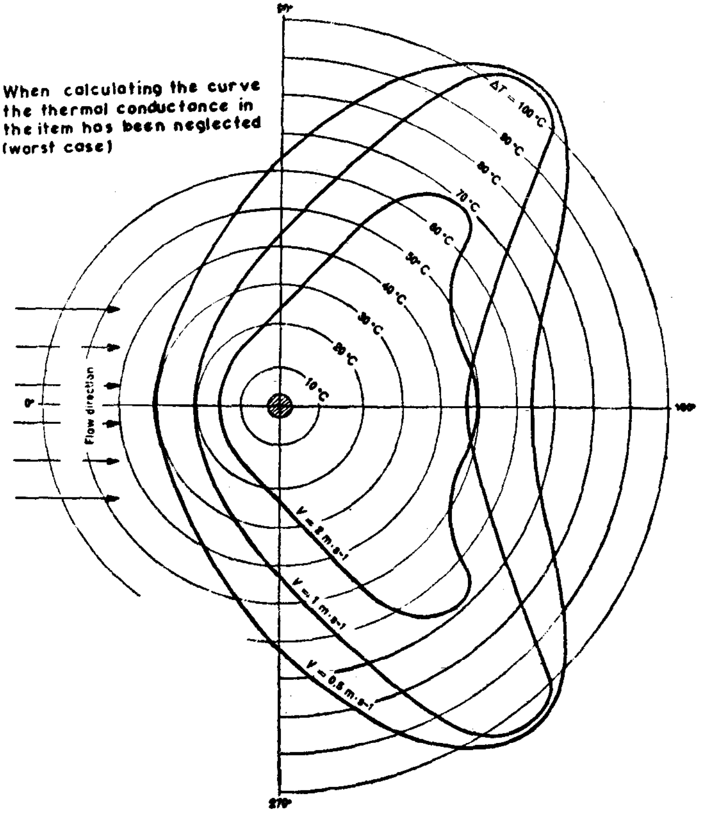


FIG. 3 EXPERIMENTAL DATA ON THE EFFECT OF AIRFLOW ON SURFACE TEMPERATURE OF A WIREWOUND RESISTOR — AXIAL AIRFLOW



When calculating the curve the thermal conductance in the item has been neglected (worst case)

ΔT is the rise in surface temperature of the item above ambient
V = air velocity $m.s^{-1}$
Air temperature = 70°C
Cylinder diameter = 6 mm
Heat dissipation per unit of surface area : 1·5 $kW.m^{-2}$

FIG. 4 TEMPERATURE DISTRIBUTION ON A CYLINDER WITH HOMOGENEOUS HEAT GENERATION IN AIRFLOW OF VELOCITIES 0·5, 1 and 2 $m.s^{-1}$

4.2 Thermal Radiation

4.2.1 The effect of emissivity coefficient of test items on temperature rise is shown in Fig. 5. This shows that heat transfer by thermal radiation cannot be neglected when test chamber conditions for testing of heat dissipating items are discussed. In the case of thermal black test items and thermal black chamber walls (emissivity coefficient approaching unity), nearly half of the heat transfer from the test item may be due to thermal radiation. Thus, if the heat dissipating test item is subjected to a certain ambient temperature in a thermal white chamber and in a thermal black chamber, the surface temperature of the test item will be significantly different. The emissivity coefficient and the temperature of the chamber walls should, therefore, be limited by specification if reproducible test results are to be achieved.

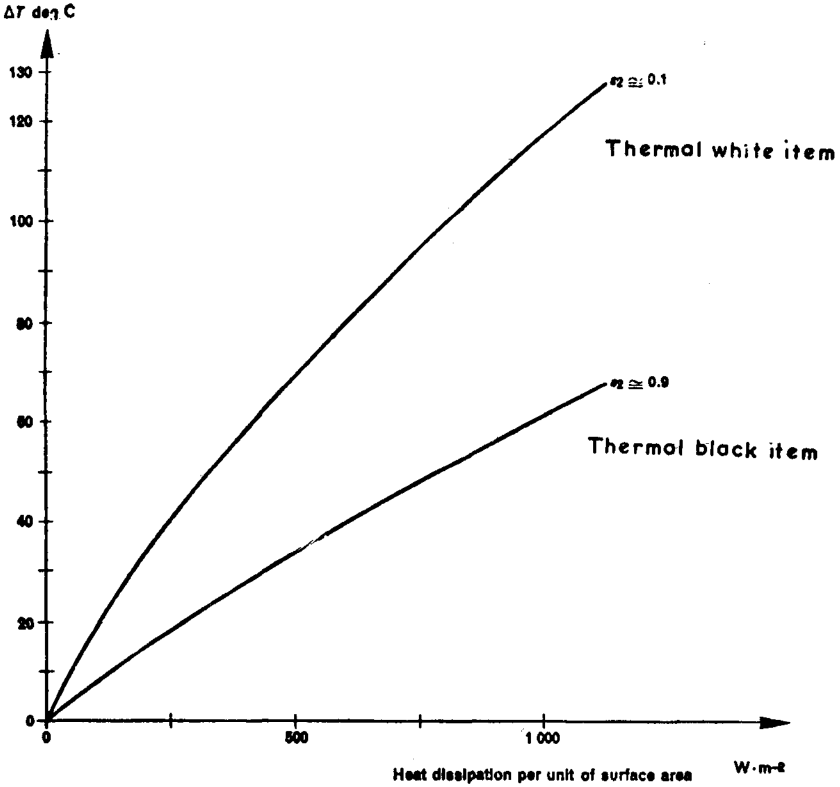
4.2.2 If the test item is sheltered from the chamber walls by other items, heating or cooling elements, mounting devices, etc, which do not comply with the requirements for thermal colour and temperature of the chamber walls, the heat radiation between the test item and the chamber walls is affected. The percentage of the chamber walls which can be 'seen' by a specific point on the test item determines the 'view factor' of that point. The view factors of each point of the test item should not be unduly disturbed by devices which do not comply with the requirements on thermal colour and temperature of the chamber walls.

4.2.3 In an ideal 'free air' condition, the heat transferred from the test item is completely absorbed by the surrounding air. This occurs as a result of free convection and complete absorption of the thermal radiation.

Most equipment and components will be operating in a surrounding which approximates more to thermal black than to thermal white.

It is furthermore easier to make the inside of a chamber approximately thermal black than to make it approximately thermal white. It is especially difficult to keep it thermal white for a long period due to ageing effects. In fact, most paints and materials (unpolished) approximate more to thermal black than to thermal white (*see* Appendix C).

If the temperature of the chamber walls varies within 3 percent of the specified test temperature in Kelvin and the emissivity coefficient varies between 0·7 to 1, the resulting variation in surface temperature of the test item will normally be less than 3 K. Since the heat radiation is proportional to the difference between the fourth power of the surface temperature of the test item and the fourth power of the chamber wall temperature, the thermal radiation is less pronounced at low temperatures and therefore the requirements on thermal colour and temperature of the chamber walls are less stringent when low temperature testing is concerned.



NOTE — *See also* Appendix D.

FIG. 5 COMPARISON OF THE TEMPERATURE RISE AS A FUNCTION OF HEAT DISSIPATION FOR THERMAL WHITE AND THERMAL BLACK ITEMS SUBJECTED TO AN AMBIENT TEMPERATURE OF 70°C IN A CHAMBER WITH THERMAL BLACK WALLS (EXPERIMENTAL VALUES)

4.2.4 The heat transfer due to thermal radiation is considerably dependent on the temperature of the chamber walls. This dependence is the main reason why testing with forced air circulation cannot be used without corrections in accordance with Appendix D when the difference between the surface temperature of the item and the temperature of the ambient air is significant.

4.3 Thermal Conduction

4.3.1 Heat dissipation by thermal conduction depends on the thermal characteristics of mounting and other connections.

4.3.2 Many heat dissipating equipment and components are intended to be mounted on heat sinks or other well-conducting devices, with the result that a certain amount of heat is effectively dissipated through thermal conduction.

The relevant specification shall then define the thermal characteristics of the mounting and these should be reproduced when the test is made.

4.3.3 If an equipment or component can be mounted in more than one manner with different values of thermal conduction, the worst case should be covered. The worst case is different for differing applications as follows:

a) *Dry heat testing of heat dissipating items* — Since heat is transported in the direction from the test item to the mounting devices, the worst case is reached when this transfer is as small as possible, that is, when the mounting has low thermal conductivity (thermally isolated).

b) *Dry heat testing of non-heat dissipating items* — As long as thermal stability has not been reached, the heat is transferred from the chamber walls through the mounting devices to the test item. The worst case is then where the thermal conductivity of the mounting is high. The thermal capacity of the mounting should be low in order to avoid a considerable warm-up time of the mounting and accordingly a delay in the heat transfer from the chamber walls to the test item.

c) *Cold testing of heat dissipating items and non-heat dissipating items* — Since heat is transferred from the test item to the chamber walls through the mounting devices, the worst case (lowest temperature of the test item) is reached when this transfer is as effective as possible, that is, when the thermal conductivity of the mounting is high.

4.4 Forced Air Circulation

4.4.1 Where the chamber is large enough to comply with the requirements in Appendix B, the heating and cooling of the chamber may necessitate forced air circulation.

In such cases, a check is made, at laboratory temperature inside the chamber, that the temperature at representative points on the surface of the test item is not unduly influenced by the air velocity used in the chamber. If the surface temperature at any point of the test item is not reduced by more than 5°C by the influence of the forced air circulation used in the chamber, testing is performed as in a chamber with no forced air circulation, and the cooling effect of the forced air circulation is neglected since it may be assumed to be reasonably small.

4.4.2 Where the chamber is too small to comply with the requirements of Appendix B, or where the reduction of surface temperature as measured in **4.4.1** exceeds 5°C, an exploratory test should be made outside the test chamber.

4.4.3 The temperatures of a representative number of points on the surface of the test item are measured in the laboratory outside the chamber in order to give a basis for calculation of the surface temperatures at the specified test conditions. These measurements are carried out under those load conditions which are specified for the test temperature by the relevant specification.

For small temperature differences ($\Delta T1$) between ambient temperature and surface temperature, this difference ($\Delta T1$) can be assumed to be the same in different ambient temperatures as long as the differences ($\Delta T2$) in ambient temperatures are small.

The error is within 3°C if $\Delta T1 < 25°C$ and $\Delta T2 < 30°C$.

The relationship between surface temperatures at different ambient temperatures is given in Appendix D. With nomograms specified in Appendix D, it is possible to calculate the surface temperature at any ambient temperature if the surface temperature at a certain ambient temperature is known. By using the nomogram, it is possible to extend the range where the surface temperatures in specified test conditions can be calculated if they are known at laboratory temperature. The nomograms in Appendix D can be used to at least $\Delta T1 = 80°C$ and $\Delta T2 = 65°C$.

4.4.4 The choice of representative points to be checked when the alternative first and second methods are used should be based on a detailed knowledge of test item (thermal distribution, thermally critical points, etc). Since such a choice is mainly a matter of skilled judgement, the preferred method where no forced air circulation is used is strongly recommended for type approval purposes because of its higher degree of reproducibility.

One exploratory test may cover the chamber performance for a long series of similar tests (for example, on similar components), whereas in other cases an assessment may need to be made prior to each test (for example, for different equipment).

5. TEST CHAMBERS

5.1 General — It is not practical for testing purposes to try to reproduce free air conditions, but it is, however, possible to simulate the effects of these conditions.

Even in very large chambers, the air circulation and temperature distribution around the test item will not be identical with actual free air conditions.

Nevertheless, it is established by experimental results and test experience that a reasonably large chamber with no forced air circulation will affect the temperature of the test item in approximately the same way as would free air conditions.

The requirements on size of chamber in relation to the size and heat dissipation of the test item, which are necessary for simulating the effects of free air conditions, are given in Appendix B.

The requirements presented are valid when the ambient temperature is monitored in the lower part of the testing chamber, where the air is not greatly affected by the heat convection from the test item.

However, in some cases difficulties in testing with no forced air circulation arise. In a number of existing chambers the heating or cooling of the chamber cannot be performed without forced air circulation, especially for testing of large items, or many components in the same chamber.

Table 1 shows the parameters of a test chamber that will have a considerable influence on the test results of a heat dissipating item.

TABLE 1 PARAMETERS OF TEST CHAMBER HAVING CONSIDERABLE INFLUENCE ON THE TEST RESULTS OF A HEAT DISSIPATING ITEM

Transfer Mechanism	Convection		Radiation	Conduction
	Free Air	Forced Air Circulation		
Chamber parameters	Dimensions; air temperature	Air velocity; air temperature	Wall temperature; wall emission; view factor	Thermal characteristic of mounting

5.2 Methods of Achieving the Required Conditions in the Test Chamber

5.2.1 *Design of Chambers for Simulating the Effect of Free Air Condition* — Heating and cooling elements should not be situated in the working space, as the controlling of the chamber temperature involves changes in the temperatures of these elements. Large fluctuations in the temperature of the chamber walls should be avoided in order to minimize radiation problems.

For the best results, all the walls of the chamber should be heated. Liquid circulation provides a convenient method of heating or cooling all walls without large fluctuations in walls temperature. The walls of the chamber should fulfil the emissivity requirements of the test.

Where a chamber relies on air circulation for maintenance of the test temperature, it may be possible to place the test item inside a box which is then placed in a chamber. The volume of the box should fulfil the dimensional requirements of the test and the walls should meet the emissivity coefficient requirements.

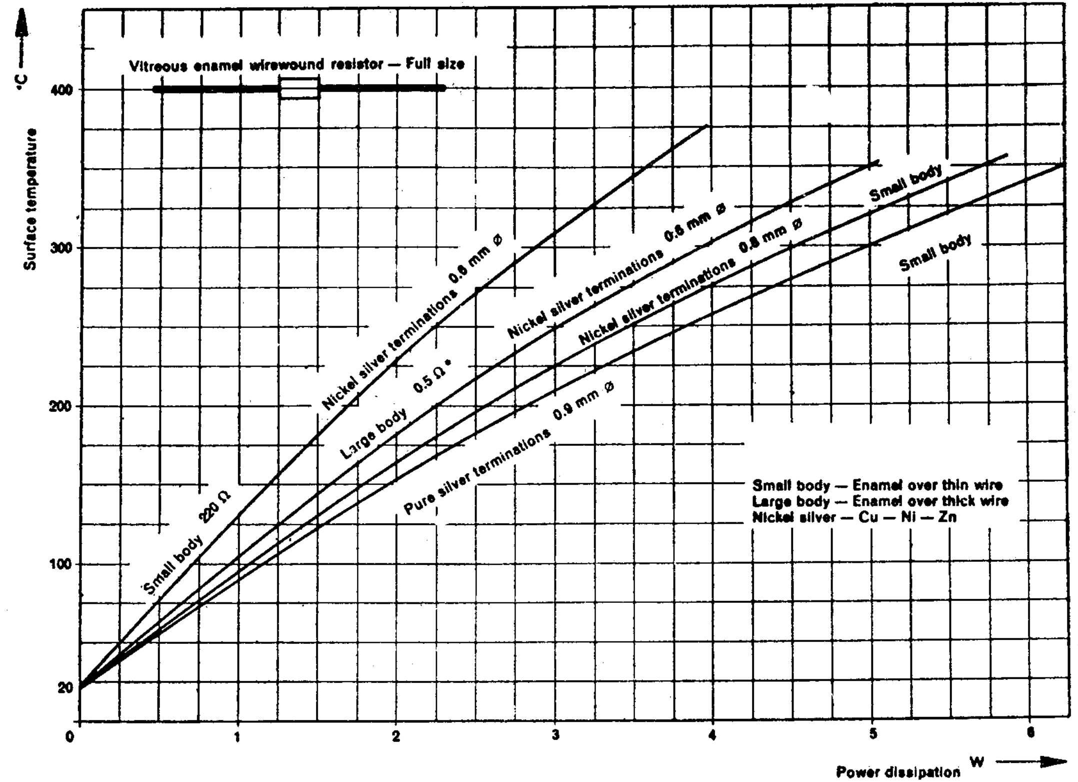
5.2.2 *Design of Chambers with Forced Air Circulation* — A chamber with an airflow is intended for use with items which make the use of a free air chamber impracticable either by virtue of their large size or high dissipation. All the requirements for free air chambers thus apply except for those relating to dimensions.

The airflow should be large enough to ensure that the item is not overheated, yet should not be so large that excessive cooling of the item can occur. The effects of airflow are given in more detail in Appendix A. In practice, an airflow of 0·5 m/s has been found to represent a fair compromise, although facility to vary the rate of flow is a useful advantage.

The airflow should be as uniform as possible. The airflow should be directed vertically upward to minimize the variation from that which would occur due to convection above. If the fan causes a pressure build-up in an antechamber, from which the air is allowed to escape through a filter (for example, fibre-glass mat) a uniform airflow results. This antichamber may also contain the heaters which control the chamber temperature. Alternatively, the heaters and filter may be combined by the use of woven mesh heaters.

5.2.3 *Emissivity Coefficient of Walls* — The walls of the chamber should be thermal black if free air conditions in infinite space are to be simulated. Table 3 of Appendix C indicates that an emissivity coefficient of 0·70 may easily be achieved. Most matt paints are perfectly satisfactory for the treatment of chamber walls operating at moderate temperatures.

5.2.4 *Thermal Characteristics of Mounting Devices* — Reference should be made to **4.3** and Fig. 6 where some characteristics for wire terminations are given. Reference should also be made to Appendix E which gives thermal conductivities of various materials. In cases where conduction



*NOTE — The thick wire used for the resistor winding also helps to conduct heat rapidly from the ' hot spot '

FIG. 6 EFFECT OF WIRE TERMINATION DIMENSIONS AND MATERIAL ON SURFACE TEMPERATURE OF A COMPONENT

by a mounting and/or terminations, such as lead wires, becomes important, it is essential that a constant length of such wire terminations is used for all tests.

6. MEASUREMENTS

6.1 Temperature — Measurements of temperature at various points on or in an item are necessary for the purposes of tests involving heat dissipating items in conditions other than ' free air '.

6.1.1 Guidance for such measurements are given in Appendix F.

6.2 Air Velocity — A knowledge of the velocity of the air in the test chamber, while not essential for specification of the tests, is nevertheless most useful, for example, to ensure uniformity of conditions within the chamber in the case of testing multiple items in the same chamber with forced air circulation.

6.2.1 Guidance for such measurements is given in Appendix G.

6.3 Emissivity Coefficient — Since the transfer of heat by radiation is important in the case of testing of heat dissipating items, the emissivity coefficient of the walls of the chamber shall be measured and periodically checked.

6.3.1 Guidance for such measurements is given in Appendix C.

7. TESTING OF ITEMS THAT DO NOT ACHIEVE TEMPERATURE STABILITY DURING THE TEST

7.1 General

7.1.1 Certain items are used or stored under high or low temperature conditions only for periods shorter than the time for achieving temperature stability. Cold or dry heat tests of such equipment according to IS : 9000 (Part II)-1977* or IS : 9000 (Part III)-1977† where the duration of the test is counted from the time at which the item has reached temperature stability may then overstress the equipment.

7.1.2 When such an overstress is to be avoided, the procedures defined in dry heat tests or cold tests may be used with the deviations and precautions given in **7.2**.

7.1.3 Examples where this may be the case are certain aircraft and missile equipment.

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*Basic environmental testing procedures for electronic and electrical items: Part II Cold test.

†Basic environmental testing procedures for electronic and electrical items: Part III Dry heat test.

7.1.4 Although equipment with large thermal time constants, compared to diurnal temperature fluctuations are normally tested according to cold and dry heat tests under temperature stability conditions, there are cases where a close simulation of the actual environment is desired. In such cases, a test without temperature stability of the item may be used.

7.1.5 Testing for a period shorter than the time for achieving temperature stability may be relevant also for the cases where a high or low temperature in a large equipment (for example, power supply transformers and motors with high thermal time constant) is required to be obtained in a short time. In such cases, the test ambient temperature is chosen higher or lower than the ambient temperature which is expected in conditions where the equipment is to be used.

7.2 Testing Precautions — In order to achieve reproducibility, the cold and dry heat tests shall be so designed that the coldest (hottest) temperature attained in a certain point of the item will be the same independent of the testing laboratory. For the design of a test with a short test duration compared to the time needed for the item to attain temperature stability the precautions spelt out in **7.2.1** to **7.2.1.4** shall be taken into account.

7.2.1 *Velocity of the Air Surrounding the Test Item*

7.2.1.1 The efficiency of the heat exchange between the test chamber air and the test item depends on the air velocity.

7.2.1.2 A close simulation of air velocities connected with high (low) temperatures in the actual environment is desirable. Due to limited knowledge of the actual environment as well as difficulties in providing defined air velocities (including degree of turbulence, etc) in testing chambers, such simulation is normally not feasible. Therefore, a worst case shall normally be used for testing to cover all possibilities.

7.2.1.3 In the case of testing *non-heat dissipating items*, a higher air velocity results in a higher (for cold testing, lower) item temperature. It is, therefore, recommended to use a high air velocity in the test chamber for this test (preferably not less than 2 m/s measured in the empty working space).

7.2.1.4 In the case of testing *heat dissipating items*, a higher air velocity decreases the temperature of the hottest points of the test item if this temperature is above the temperature of the surrounding air. As this is mostly the case such testing shall be performed, whenever possible, with no forced air circulation (free air conditions). The alternative method given in Section 5 of IS : 9000 (Part III)-1977* [Section 4 of IS : 9000 (Part II)-1977†] may be used where the heating (cooling) of the chamber may only be carried out by circulation of air.

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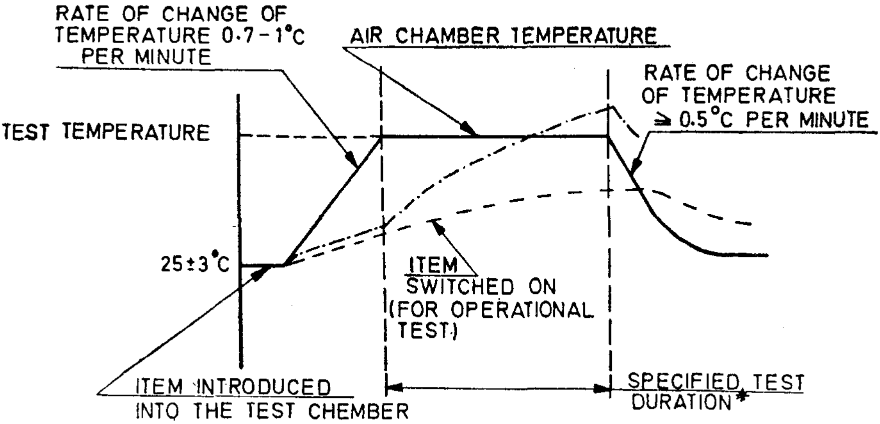
*Basic environmental testing procedures for electronic and electrical items: Part III Dry heat test.

†Basic environmental testing procedures for electronic and electrical items: Part II Cold test.

7.2.2 *Conditioning* — In order to achieve reproducibility the temperature-time history of the chamber air shall be well defined for the whole conditioning period. In cases where a close simulation of the actual environment is feasible this temperature-time history may be designed specifically for the case to be simulated. In more general testing the temperature-time history recommended in Fig. 7 may be followed.



– – – – – – Temperature of a non-heat dissipating item

– · – · – · – Temperature of a heat dissipating item

*NOTE — The specified test duration is counted from the time when the chamber air first achieves a temperature within 3°C of the specified test temperature.

FIG. 7 RECOMMENDED TEMPERATURE — TIME HISTORY

It should be noted that this temperature-time history differs from cold and dry heat tests in the following details:

a) Narrower limits of the start temperature (for example, 27 ± 3°C);

b) Specification of the rate of change of chamber air temperature during the establishment of the test temperature; and

c) The specified test duration is counted from the time when the chamber air temperature reaches the specified value.

APPENDIX A

(*Clauses* 4.1.2 *and* 5.2.2)

EFFECT OF AIRFLOW ON CHAMBER CONDITIONS AND ON SURFACE TEMPERATURES OF TEST ITEMS

A-1. CALCULATION OF THE EFFECT ON AIRFLOW ON ITEM TEMPERATURE AND ON TEMPERATURE GRADIENT IN THE CHAMBER

A-1.1 Letter Symbols Used

v = air velocity ($\mathrm{m.s^{-1}}$)
$\lambda(v)$ = heat transfer coefficient ($\mathrm{W.m^{-2}.K^{-1}}$)
P = quantity of heat transferred in unit time (W)
F = effective area of the heat dissipating surface ($\mathrm{m^2}$)
t = time
G = Mass of incoming or outgoing air per unit time ($\mathrm{kg.s^{-1}}$)
C_p = specific heat of air at constant pressure ($1\,000\,\mathrm{J.kg^{-1}.K^{-1}}$)
γ = density of air ($1{\cdot}29\ \mathrm{kg.m^{-3}}$)
S = cross-sectional area of chamber ($\mathrm{m^2}$)
T = temperature (K)

A-1.2 Temperature of Test Item

$$T = \frac{1}{\lambda(v)} \cdot \frac{P}{F}$$

where

$$\lambda(v) = a + bv$$

$$a \cong 10$$

$$v < \frac{a}{b} < 3\ \mathrm{m.s^{-1}}$$

Experimental results indicate that, at the low air velocities relevant to the tests, $b \cong 3$; b increases with increasing air velocity; at $v = 3\ \mathrm{m.s^{-1}}$, $b \cong 8$.

If $v = 0{\cdot}3\ \mathrm{m.s^{-1}}$, the error in $T \leqslant 10$ percent

A-1.3 Gradient Between Incoming and Outgoing Air

$$\Delta T_{\mathrm{air}} = \frac{P}{C_p\, G} = \frac{P}{C_p\, Sv\, \gamma}$$

Substituting numerical values for a cubic chamber of 0·5 m side with an airflow of 0·3 ms^{-1} and a power dissipation within the chamber of 100 W: $S = 0{\cdot}25\ m^2$

$$\Delta T_{al} = \frac{100}{1\,000 \times 0{\cdot}25 \times 0{\cdot}3 \times 1{\cdot}29} \cong 1°C$$

Up to 100 W dissipation, there is little problem. At 1 kW, a large chamber is needed (for example, a cubic chamber of side of about 1·5 m). A faster airflow can be used if the gradient is acceptable.

APPENDIX B

(*Clauses* 4.1.3, 4.4.1, 4.4.2 *and* 5.1)

EFFECTS OF SIZE OF CHAMBER ON SURFACE TEMPERATURE OF AN ITEM WHEN NO FORCED AIR CIRCULATION IS USED

B-1. ACCEPTABLE CHAMBER SIZE

B-1.1 The results of a series of experiments which have been made in order to determine the minimum acceptable size of chamber for dry heat testing in which for a certain test item the surface temperature on the item will be approximately the same as in ‘ free air ’ conditions are shown in Fig. 8.

B-1.2 Items with different sizes and variable heat dissipation per unit surface have been subjected to an ambient temperature [defined as in IS : 9000 (Part I)-1977*] of +70°C in dry heat test chambers of different sizes. The criterion for the acceptable size of chamber was the requirement that the surface temperature of the test item shall not be allowed to deviate more than 5°C from the surface temperature attained in the biggest chamber, which was very large compared with the sizes of the test items. The walls of the chambers were kept within 5°C of the ambient temperature.

B-1.3 The test items were cubical and almost thermal white in order to give the worst case where almost all heat was dissipated through convection. The chamber walls were close to thermal black.

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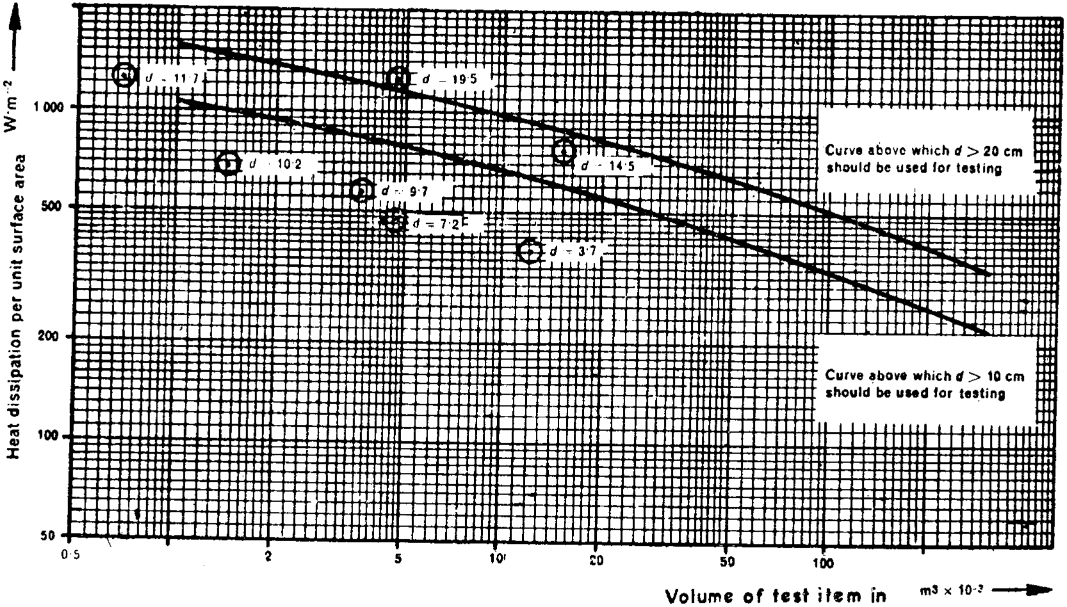
*Basic environmental testing procedures for electronic and electrical items: Part I General.



⦿ = experimental data

d = distance in centimetres between the surface of the test item and the chamber wall

FIG. 8 HEAT DISSIPATION PER UNIT SURFACE AREA OF THE TEST ITEM AT WHICH THE DEVIATION BETWEEN THE SURFACE TEMPERATURE OF THE ITEM IN A VERY LARGE CHAMBER AND IN A SMALLER CHAMBER REACHES 5 deg C

APPENDIX C

(*Clauses* 4.2.3, 5.2.3, 6.3.1 *and* F-3.1)

MEASUREMENT OF EMISSIVITY COEFFICIENT

C-1. GENERAL

C-1.1 As indicated in Appendix F, heat transfer by radiation between two bodies at different surface temperatures, for example, between an item under test and the walls of a test chamber, is governed by their emissivities. Thus, the emissivity coefficients of the surfaces participating in the exchange of radiation shall be known in order to enable the behaviour of items under operational conditions to be assessed from the test results. This applies particularly to heat dissipating items.

C-1.2 This appendix deals mainly with methods of measurement of emissivity coefficient that provide sufficient accuracy and are suitable for practical environmental testing, and also require a comparatively small amount of apparatus and time.

C-1.2.1 Precision measurements as well as emissivity coefficient measurements in outer space simulation chambers call for more expensive methods. When solar irradiation is included the differing spectral ranges of incoming and outgoing radiation, and hence the degree of absorption of the irradiation, shall be taken into account. With respect to these methods reference should be made to the relevant literature.

C-2. RADIATION THEORY

C-2.1 The radiation theory given below relates to the measurement methods covered in **C-4**.

The radiation power M emitted into the hemisphere from unit surface of a real body at a certain temperature is related to the corresponding radiation power M_s of a black body at the same temperature by the expression:

$$M = \varepsilon . M_s$$

M_s is given by the Stefan-Boltzmann law

$$M_s = \sigma . T^4 \qquad \dots\dots\dots (1)$$

where

T is the temperature in K and σ is Stefan-Boltzmann's constant

$$\sigma = 5{\cdot}67.10^{-8}\ \text{W.m}^{-2}.\text{K}^{-4}$$

ε is termed the 'hemispherical total emissivity coefficient'. The spectral distribution of the radiation of a black body at temperature T is given by Planck's radiation law and the wavelength λ_{max} of the maximum of radiation intensity is given by Wien's displacement law:

$$\lambda_{max}.T = 2{\cdot}89.10^{-3}\ \mathrm{m.K} \qquad \ldots\ \ldots\ \ldots\ (2)$$

In practice, equation (1) is usually employed in the following form:

$$M_s = C_s . \left(\frac{T}{100}\right)^4$$

$$C_s = 5{\cdot}67\ \mathrm{W.m^{-2}.K^{-4}} = 20{\cdot}4\ \mathrm{kJ.m^{-2}.h^{-1}.K^{-4}}$$

where

h = time in hours.

The following thus holds for a real body:

$$M = C.\left(\frac{T}{100}\right)^4 = \varepsilon.C_s.\left(\frac{T}{100}\right)^4 \qquad \ldots\ \ldots\ \ldots\ (3)$$

For the radiation exchange between two bodies at temperatures T_1 and T_2, the heat flow per surface unit Q_{12} is given by:

$$Q_{12} = \varepsilon_{12}.C_s.\left\{\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right\} \qquad \ldots\ \ldots\ \ldots\ (4)$$

The radiation exchange figure ε_{12} depends on the geometry and the emissivity coefficients ε_2 (of the item) and ε_1 (of the chamber walls) of the participating surfaces.

For the case, frequently encountered in environmental testing, of a three dimensional item within a closed test chamber, the radiation exchange formula for two concentric spheres or cylinders of infinite length, one surrounding the other is considered. Assuming diffuse reflection and the validity of Lambert's law, the following equation is obtained:

$$\varepsilon_{12} = \frac{\varepsilon_2}{1 + \frac{A_2}{A_1}\left(\frac{\varepsilon_2}{\varepsilon_1} - \varepsilon_2\right)}, \qquad \ldots\ \ldots\ \ldots\ (5)$$

where

A_1 and A_2 are the surface areas concerned.

In practice, this means that the smaller the surface A_2 (of the item) with respect to the surface A_1 (of the chamber walls), the smaller will be the influence of the emissivity coefficient ε_1 of the chamber walls on the radiation exchange figure ε_{12}.

C-3. PRACTICAL APPLICATIONS OF RADIATION THEORY

C-3.1 Error Magnitudes — A logarithmic differentiation of equation (3) yields:

$$\frac{dM}{M} = \frac{d\varepsilon}{\varepsilon} + 4\frac{dT}{T} \qquad \text{... ... ... (6)}$$

If ε is to be determined, the attainable accuracy is given by the error of the measurements of both T and M. Since, with normal testing procedures (apart from outer space simulation), T ranges between about 200 K and 400 K, a temperature measurement error of 0·25 K at, for example, 200 K entails an overall error of 0·5 percent. With the radiation exchange method, the errors of two temperature measurements are of importance, that is, accurate measurement of both temperature difference $| T_1 - T_2 |$, and one of the two temperatures, T_1 or T_2 is essential.

Both M and Q involve electrical power which is dissipated in the item and given up *via* its surface. This power becomes equal to the radiation power given up only when heat transfer by convection has become zero (hence only at barometric pressures below about 0·01 Nm^{-2} and when no heat is conducted away *via* the mounting).

C-3.2 Wavelength Range and Energy Distribution of the Temperature Radiation — Figure 9 shows the wavelengths λ_{max} for various temperatures in Kelvin where, according to Wien's displacement law (equation 2), the intensity of temperature radiation becomes a maximum. Within the temperature range of particular interest for environmental testing λ_{max} is mostly in the far infra-red.

When Planck's law, in a reduced form, is integrated from 0 to λ and this amount $M_{o....\lambda}$ is related to the total radiation M_s with the same temperature T, the values of Fig. 10, result as a function of $\lambda.T$ and λ/λ_{max} respectively.

Obviously, the fraction of radiation from 0 to λ_{max} amounts to only 25 percent of the total, since 72 percent is emitted from 0 to $2\lambda_{max}$, and 88 percent of the total radiation from 0 to $3\lambda_{max}$. Radiation measurements within the above temperature range, therefore, call for radiation detectors that remain sensitive in the far infra-red. Material useful for the optical system of such a device is, for instance, KRS 5 (44 percent TlBr and 56 percent TlI) with wavelength limit of about 45 µm.

C-3.3 Total Radiation — The values of the specific total radiation calculated for a number of temperature T from the Stefan-Boltzmann law (equation 1) are contained in Table 2. The minimum radiation power levels that can be measured with present day detectors range from 10^{-10} W to 10^{-8} W. When comparing these detectable radiation power levels with

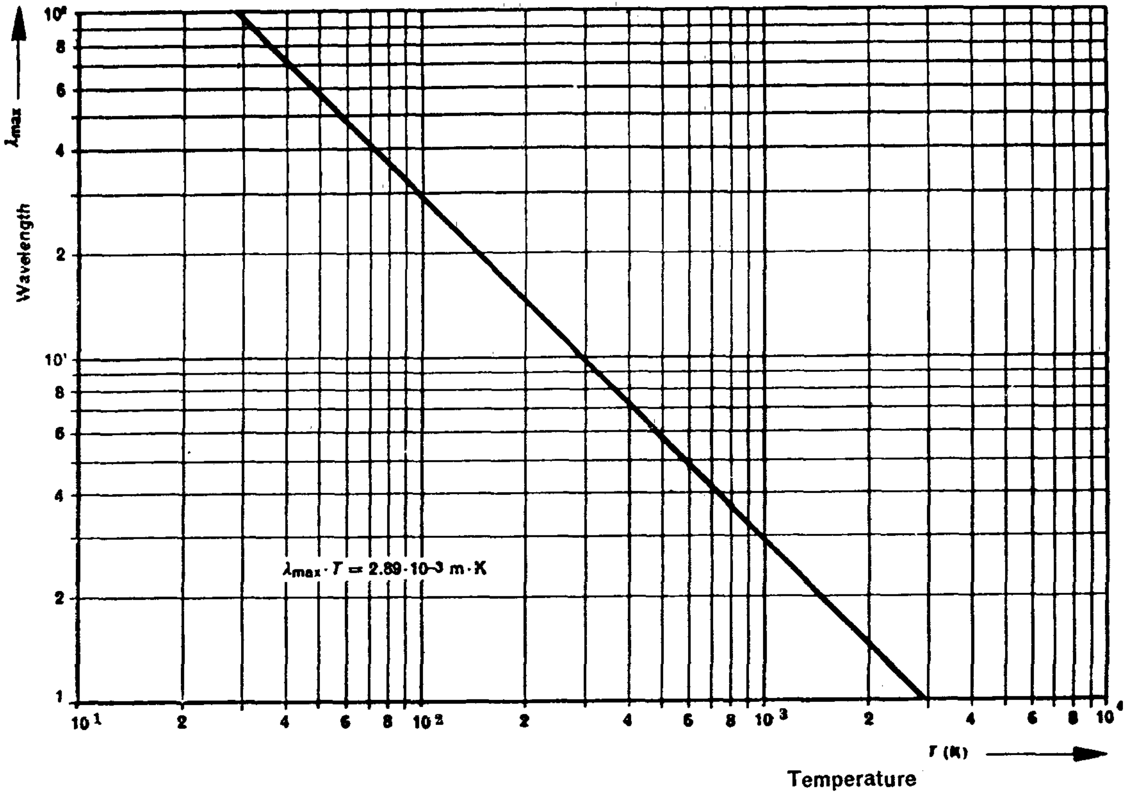


FIG. 9 WIEN'S DISPLACEMENT LAW

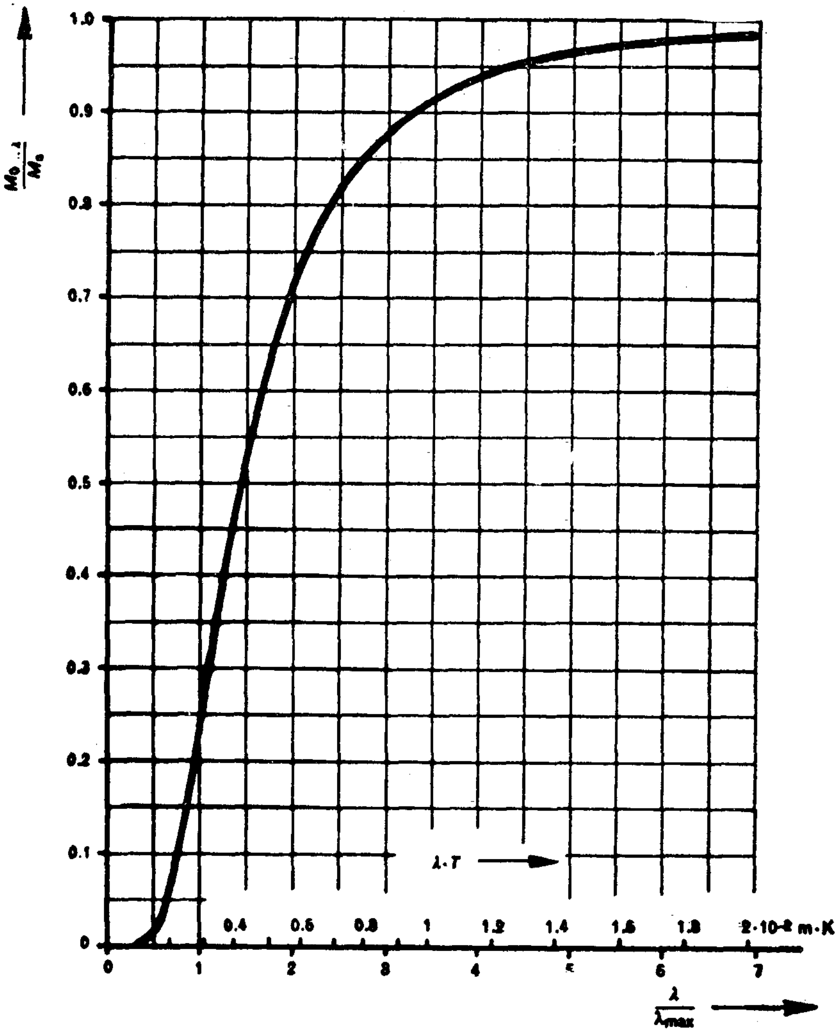


FIG. 10 RELATION BETWEEN $\frac{M_{0...\lambda}}{M_s}$ AND $\lambda.T$

those of Table 2 it should be noted that the surface, from which the radiation is picked up, subtends a spatial angle at the detector which represents only a very small portion of the hemisphere. The emissivity coefficient ε_n for radiation normal to the surface is measured in this case.

TABLE 2 HEMISPHERICAL TOTAL RADIATION FOR VARIOUS TEMPERATURES

(*Clause* C-3.3)

T	M_s	T	M_s
(1)	(2)	(1)	(2)
K	W.m^{-2}	K	W.m^{-2}
4	$1{\cdot}45.10^{-5}$	300	459
10	$5{\cdot}67.10^{-4}$	400	1 450
50	$3{\cdot}54.10^{-1}$	500	3 540
100	5·67	1 000	56 700
200	90·7	2 000	907 000

C-4. METHODS OF MEASUREMENTS OF EMISSIVITY COEFFICIENT

C-4.1 General — In the following clauses there is a review of the more general methods of measurement of emissivity coefficient of the chamber walls, applicable to cold and dry heat tests.

It should be noted that, for certain materials and treatments, the emissivity coefficient varies appreciably with temperature. Therefore, the emissivity coefficient should be measured in a temperature range appropriate to the test.

C-4.2 Measurement of the Value of the Emissivity Coefficient

C-4.2.1 *Measurement of the Surface Temperature of an Item of Known Heat Dissipation Which Exchanges Radiation with the Surrounding Wall in Vacuo* — Basically this method would best duplicate the practical conditions in the environmental simulation in test chambers if an item of known surface emissivity and with dimensions that approximate to those of the item under test is employed. The effective emissivity coefficient of the chamber walls could then be calculated from the measurements. This method can be used only if the temperature differences of the walls of the chamber are within narrow limits (that is, those prescribed for the dry heat test).

C-4.2.2 *Comparative Measurement of the Radiation Emitted from a Surface of Unknown Emissivity with the Radiation from a Surface of Known Emissivity at the Same Temperature* — Radiation detectors, having a correction setting, calibrated in terms of the emissivity coefficient ε for comparative measurement, can be used with advantage for this method.

For the calibration, a surface section immediately beside that portion of surface, the emissivity coefficient of which is to be determined is coated with a film of known emissivity. The thermal resistance between the two chosen areas should be as low as possible in order that the two surfaces should be at the same temperature.

The radiation temperature of the area of known emissivity is first measured with the emissivity coefficient scale set to the known value. The detector is then directed towards the surface under test and the emissivity coefficient scale is adjusted until the same radiation temperature reading as hitherto is obtained. The value of ε thus read off from the emissivity coefficient scale represents an average value, which is higher than the true value. The instrument detects both reflected and emitted radiation; the quantity of the former varying with the distance between the surface and the detector. Since the average value of ε includes the contributions of both types of radiation, whereas the true value of ε relates only to emitted radiation, it follows that the average value of ε is higher than the true value. Nevertheless, for most practical purposes, the accuracy of the method is sufficient.

If more accurate measurement is necessary, this can be made using reference standards of known emissivity coefficient, which are compared with test pieces of wall removed from the chamber. Specialized equipment and personnel are required.

C-4.3 Check to Ensure that a Minimum Value of Emissivity Coefficient is Exceeded — For cold and dry heat tests, the requirements for emissivity coefficients of chamber walls are given as minimum values. Therefore, it is, in many cases, sufficient to check that the emissivity coefficient of the chamber walls is above a certain value. This can be done by mounting on the chamber wall a plate, the emissivity coefficient of which is equal to the minimum value specified. By scanning both walls and plate with a radiation detector it is necessary to note only whether the plate appears ‘ whiter ’ or ‘ blacker ’ than the chamber walls.

C-5. EMISSIVITY COEFFICIENT VALUES

C-5.1 Numerous emissivity coefficient values of various materials are available in the literature and in Table 3.

C-6. METHODS OF INCREASING THE EMISSIVITY OF TEST CHAMBER WALLS

C-6.1 Coatings and Other Surface Treatments — For the purpose of obtaining emissivity coefficients greater than the minimum values specified for cold and dry heat tests, it is possible to use a suitable lacquer or other surface treatment (for example, sand blasting, chemical blackening).

It should be noted that thermal black does not necessarily mean that the optical colour of the chamber wall should be black; even coating with a suitable matt white lacquer has been found to be acceptable.

C-6.2 Mechanical Structures — The emissivity can be considerably increased by the mounting of honeycomb structures on the chamber wall. The method is mainly applied to outer space simulation chambers. It is less suitable for test chambers that are also run with humid atmospheres since any cleaning of the chamber walls which may be required is difficult to carry out.

C-7. VALUES OF EMISSIVITY COEFFICIENT

C-7.1 Table 3 gives, for a selection of materials, the emissivity coefficient for the hemispherical total radiation ε, and for radiation normal to the surface ε_n.

In general, for plain metallic surfaces the average $\varepsilon/\varepsilon_n = 1{\cdot}2$; for other bodies with smooth surfaces $\varepsilon/\varepsilon_n = 0{\cdot}95$ and for rougher surfaces $\varepsilon/\varepsilon_n = 0{\cdot}98$.

For metals, the emissivity coefficient increases with an increase in temperature, but for non-metallic materials and metal oxides the coefficient decreases as temperature rises.

TABLE 3 EMISSIVITY COEFFICIENT AT TEMPERATURE t°C

(*Clauses* 5.2.3, C-5.1 *and* C-7.1)

SURFACE	t	ε_n	
Gold, polished	130	0·018	
	400	0·022	
Silver	20	0·020	
Copper, polished	20	0·030	
Copper, polished, slightly tarnished	20	0·037	
Copper, scraped	20	0·070	
Copper, black, oxidized	20	0·78	
Copper, oxidized	130	0·76	0·725
			0·049
Aluminium, bright, rolled	170	0·039	
	500	0·050	
Aluminium, bronze paint	100	0·20-0·40	
Aluminium silicon, cast, polished	150	0·186	
Nickel, clean matt	100	0·041	0·046
Nickel, polished	100	0·045	0·053
Manganese, bright rolled	118	0·048	0·057
Chrome, polished	150	0·058	0·071

(*Continued*)

TABLE 3 EMISSIVITY COEFFICIENT AT TEMPERATURE t°C — *Contd*

SURFACE	t	ε_n	ε
Iron, clean, etched	150	0·128	0·158
Iron, clean, rubbed (emery)	20	0·24	
Iron, red rusted	20	0·61	
Iron, rolled	20	0·77	
	130	0·60	
	100	0·80	
Iron, cast	20	0·85	
Iron, heavily rusted	80	0·613	
Iron, oxidized	200	0·639	
Steel, stainless (X5CrNi189), polished	50	0·11	0·11
	115	0·12	0·13
	180	0·13	0·14
Sand-blasted	− 70	0·44	0·43
Roughness (arithmetical mean deviation	+ 40	0·46	0·45
Ra = 2·1 µm)	+ 150	0·48	0·47
Zinc, grey oxidized	20	0·23-0·28	
Lead, grey oxidized	20	0·28	
Bismuth, clean	80	0·340	0·366
Large grain emery	80	0·855	0·84
Clay, baked	70	0·91	0·86
Radiator varnish	100	0·925	
Red lead paint	100	0·93	
Enamel, lacquer	20	0·85–0·95	
Black matt lacquer	80	0·970	
Bakelite lacquer	80	0·935	
Brick, mortar, plaster	20	0·93	
Glass	90	0·940	0·876
Sheet ice, water	0	0·966	0·918
Ice (rough)	0	0·985	
Waterglass, soot pain	20	0·96	
Paper	95	0·92	0·89
Beechwood	70	0·935	0·91
Roofing felt	20	0·93	

t = Temperature in degree Celsius.

ε_n = Emissivity coefficient radiation normal to the surface.

ε = Emissivity coefficient for the hemispherical total radiation.

APPENDIX D

(*Clauses* 4.2.4 *and* 4.4.3)

HEAT TRANSFER CALCULATIONS AND NOMOGRAMS

D-1. LETTER SYMBOLS

P = quantity of heat transferred in unit time (W)
A_2 = surface area of item (m^2)
A_1 = surface area of chamber walls (m^2)
T_a = temperature of chamber walls (K)
T_s = surface temperature of item (K)
ε_1 = emissivity coefficient of chamber walls
ε_2 = Stefan-Boltzmann constant:
σ = $5{\cdot}67 \times 10^{-8}$ $W.m^{-2}.K^{-4}$
a = average item dimension (m)
α = convection coefficient ($W.m^{-2}.K^{-1}$)

NOTE — The value of α is dependent on ($T_s - T_a$) and a.

D-2. HEAT TRANSFER BY RADIATION

D-2.1 The quantity of heat transferred by radiation alone from an object in a chamber to the surrounding walls is given by:

$$P = \frac{\sigma}{\frac{1}{\varepsilon_2} + \frac{A_2}{A_1}\left(\frac{1}{\varepsilon_1} - 1\right)} \cdot A_2 \left(T_s^4 - T_a^4 \right)$$

For an infinite chamber, that is, in free air, $A_1 \gg A_2$ and one obtains:

$$P = \varepsilon_2 \sigma \cdot A_2 (T_s^4 - T_a^4)$$

The same result is obtained for thermally black walls ($\varepsilon_1 = 1$) independently of chamber size.

With the abbreviation

$$F = \frac{1}{\frac{1}{\varepsilon_2} + \frac{A_2}{A_1}\left(\frac{1}{\varepsilon_1} - 1\right)}$$

the general case can be rewritten:

$$P = \sigma F A_2 (T_s - T_a) \underset{f(T_a, T_s)}{(T_s + T_a) (T_s^2 + T_a^2)} = \sigma F A_2 (T_s - T_a).$$

or $$\frac{P}{F A_2 (T_s - T_a)} = \sigma f (T_a, T_s)$$

This relation is represented in Fig. 11.

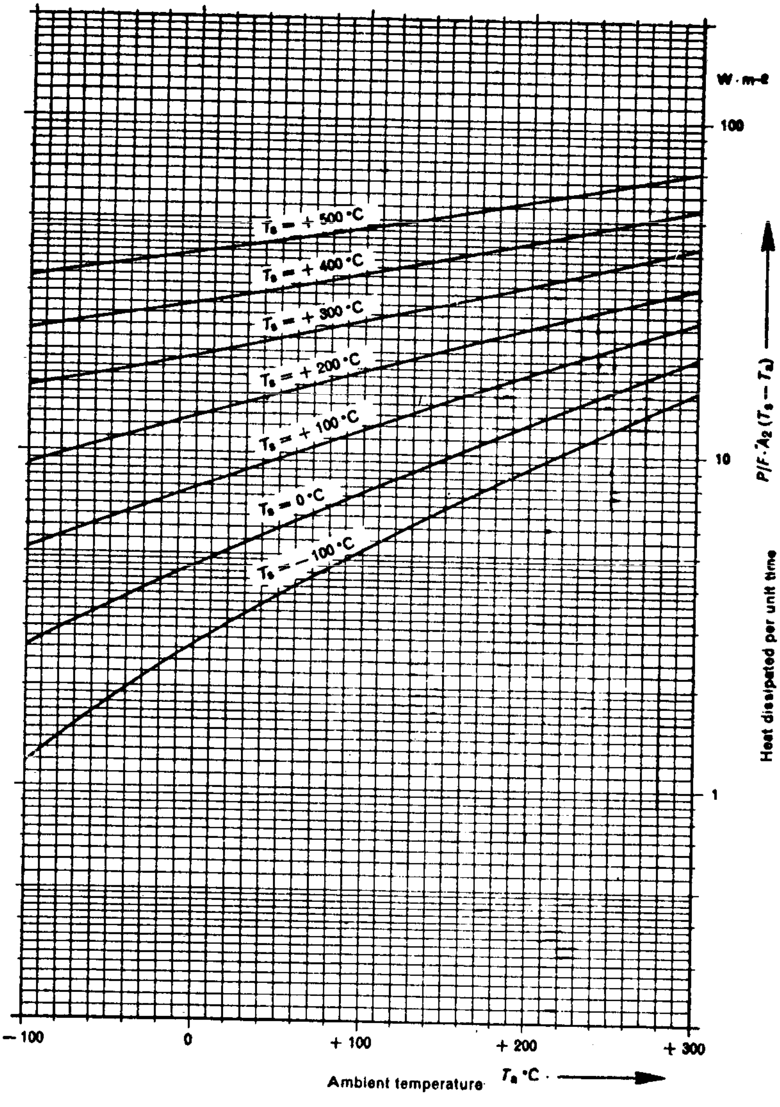


FIG. 11 RELATIONSHIP BETWEEN THE SURFACE TEMPERATURE T_s OF THE ITEM AND THE HEAT DISSIPATED P PER UNIT TIME AT THE AMBIENT TEMPERATURE T_a

D-3. HEAT TRANSFER BY RADIATION AND CONVECTION

D-3.1 Heat Transfer — Assuming that the chamber walls have the same temperature as the ambient air, one has:

$$\frac{P}{A_2} = \frac{\sigma}{\frac{1}{\varepsilon_2} + \frac{A_2}{A_1}\left(\frac{1}{\varepsilon_1} - 1\right)} \left(T_s^4 - T_a^4 \right) + \alpha \left(T_s - T_a \right)$$

For free air conditions or for black chamber walls, this simplifies to:

$$\frac{P}{A_2} = \varepsilon_2 \sigma \left(T_s^4 - T_a^4 \right) + \alpha \left(T_s - T_a \right)$$

which can be rewritten:

$$\frac{1}{\alpha} \frac{P}{A_2} = \left(T_s + \frac{\varepsilon_2 \sigma}{\alpha} T_s^4 \right) - \left(T_a + \frac{\varepsilon_2 \sigma}{\alpha} T_a^4 \right)$$

Introducing the new variables:

$$X_s = T_s + \frac{\varepsilon_2 \sigma}{\alpha} . T_s^4 \qquad X_a = T_a + \frac{\varepsilon_2 \sigma}{\alpha} . T_a^4$$

one has:

$$\frac{P}{A_2} = \alpha \left(X_s - X_a \right)$$

This relation can easily be represented by means of a nomogram. Two examples are included (*see* **D-3.2**).

D-3.2 Nomograms — From **D-1**, it is seen that α depends on $T_s - T_a$ and on the average item dimensions a. Examples of nomograms for $\varepsilon_2 = 0{\cdot}7$ based on two different values of α are given in Fig. 12 and 13.

NOTE — In the nomograms, temperatures are given in °C for convenience.

The values used for calculating the nomograms are:

	Figure 12	*Figure 13*
Average item dimension	$a = 0{\cdot}2\ m$	$a = 0{\cdot}05\ m$
Average over temperature	$T_s - T_a = 35°C$	$T_s - T_a = 100°C$
Convection coefficient for the values of item dimension and over temperature given above	$\alpha = 5\ W.m^{-2}.K^{-1}$ $\frac{\varepsilon_2 \sigma}{\alpha} = 0{\cdot}8.10^{-8}.K^{-3}$	$\alpha = 8\ W.m^{-2}.K^{-1}$ $\frac{\varepsilon_2 \sigma}{\alpha} = 0{\cdot}5.10^{-8}.K^{-3}$

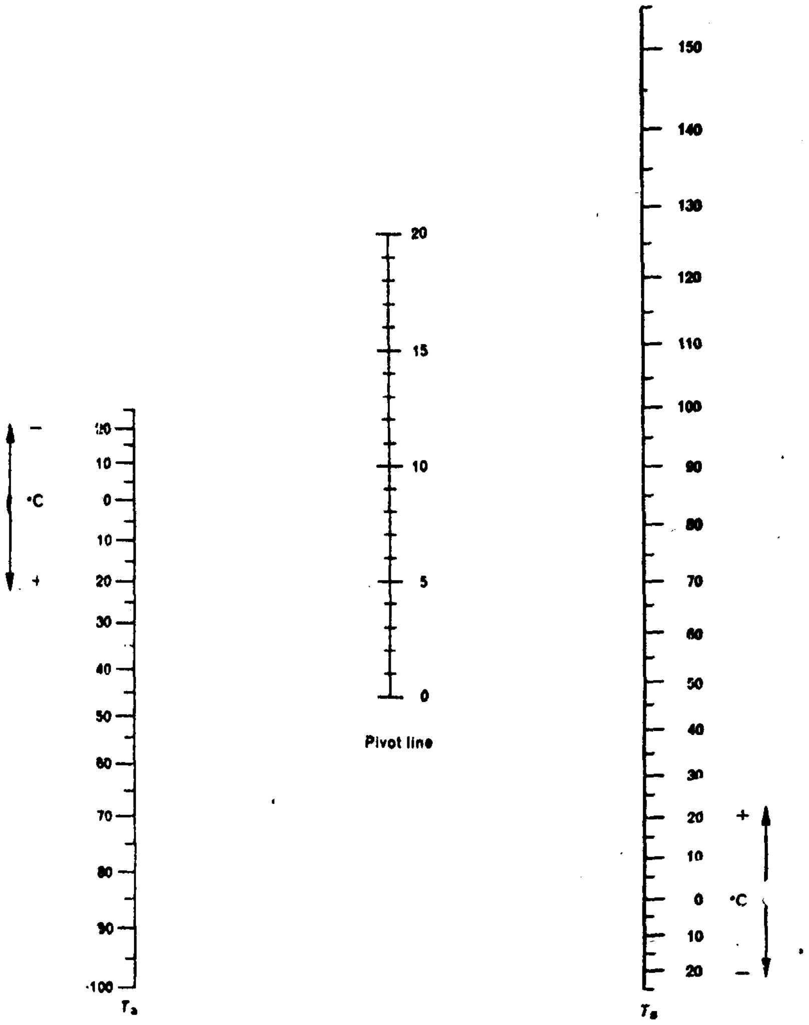


Fig. 12 Nomogram for Evaluation of Surface Temperatures of the Item T_s at Different Ambient Temperatures T_a for Average Dimensions $a = 0{\cdot}2$ m and Emissivity Coefficient $\varepsilon_2 = 0{\cdot}7$ of the Item

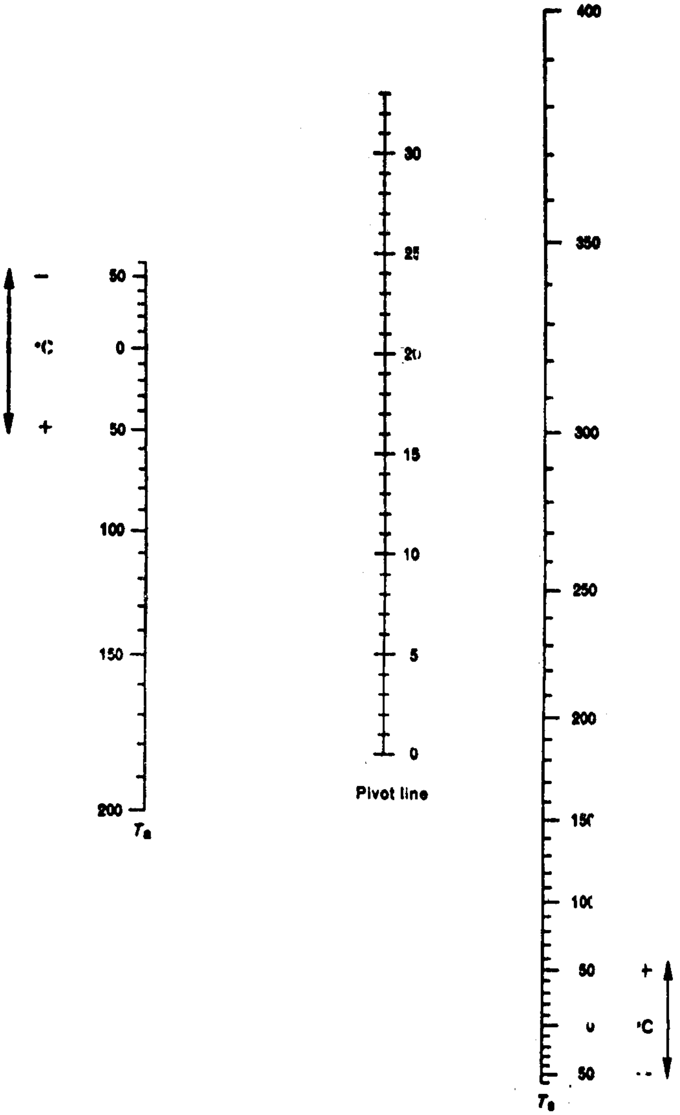


FIG. 13 NOMOGRAM FOR EVALUATION OF SURFACE TEMPERATURES OF THE ITEM T_s AT DIFFERENT AMBIENT TEMPERATURES T_a FOR AVERAGE DIMENSIONS $a = 0{\cdot}05$ m AND EMISSIVITY COEFFICIENT $\varepsilon_2 = 0{\cdot}7$ OF THE ITEM

D-3.2.1 *Example for the Use of the Nomograms*

Question : An item dissipating a certain power in free air of 20°C reaches a surface temperature of 70°C.

What will be its surface temperature when dissipating the same power in free air of 55°C ?

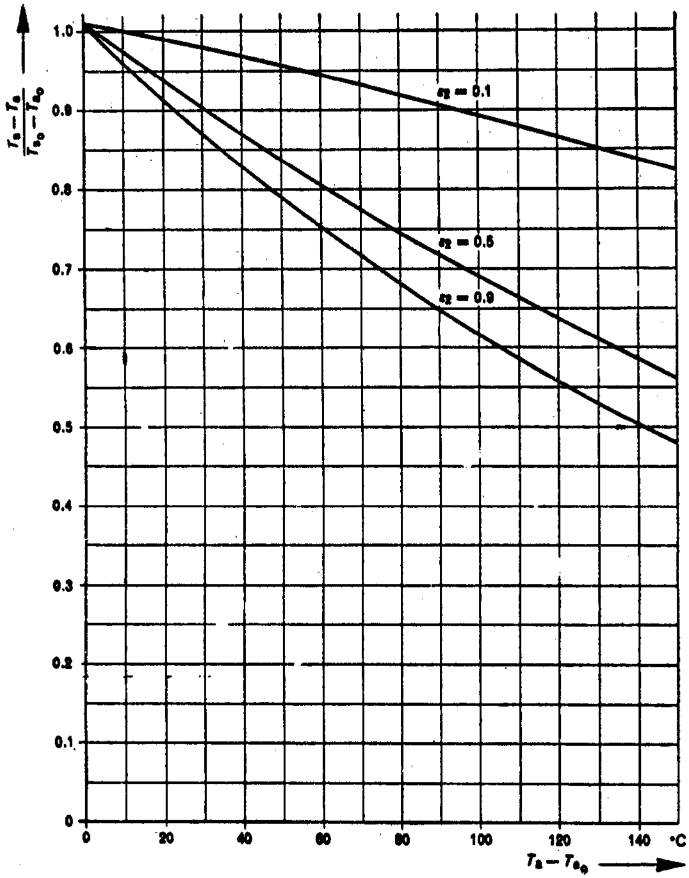
Answer : Since $T_s - T_a = 50°C$, the value of α used in the nomogram of Fig. 12 is closest to the actual value.

In Fig. 12 draw a straight line from point +20°C on scale T_a to point +70°C on scale T_s; note its intersection with THE PIVOT LINE. Now draw a straight line from point +55°C on scale T_a through this itersection point on THE PIVOT LINE and read the new intersection with scale T_s + 98°C. This is the required surface temperature.

NOTE — The dependence of the overtemperature on the emissivity coefficient ε_2 of the test item is shown in Fig. 14, for the case $a = 0{\cdot}1$ m and $\varepsilon_1 = 1{\cdot}0$ and the ambient laboratory temperature $T_{20} = 20°C$.

D-4. CORRELATION NOMOGRAMS USED IN COLD AND DRY HEAT TESTS

D-4.1 As can be seen by comparing Fig. 12 and 13, the resulting overtemperatures depend only slightly on the values of α. Therefore, only one nomogram is given in cold and dry heat tests (based on $\alpha = 5\ \mathrm{W{\cdot}m^{-2}{\cdot}K^{-1}}$).



T_{a0} = ambient laboratory temperature (+20°C)

T_{s0} = surface temperature of the item when subjected to ambient laboratory temperature in ' free air ' conditions

Average item dimension a = 0·1 m

FIG. 14 RELATION BETWEEN OVERTEMPERATURE AND EMISSIVITY COEFFICIENT ε_2 OF THE ITEM

APPENDIX E

(*Clause* 5.2.4)

THERMAL CONDUCTIVITIES OF COMMON MATERIALS

E-1. Thermal conductivities of common materials are given in Table 4. These figures are specified in SI units.

TABLE 4 THERMAL CONDUCTIVITIES OF COMMON MATERIALS

Material	Temperature t°C	Thermal Conductivity $W.m^{-1}.K^{-1}$
Silver	20	411
Copper — very pure	20	395
Copper — commercial	20	372
Gold — pure	20	311
Aluminium	20	229
Duralumin (Al-Cu)	20	165
Magnesium — pure	20	143
Elektron (Ni-St)	20	116
Brass	20	81-116
Zinc	20	113
Tin	20	66
Iron — wrought, pure	0	59
Iron	200	52
Iron — cast 3 percent carbon	20	58
Iron — chrome steel	20	40
Iron — nickel chrome steel	20	14·5
Nickel	18	59·5
Nickel — silver (Ni-Cu-Zn)	0	29·3
Lead — pure	0	35·1
Graphite — compact	20	12-174
Fireclay	100	0·5-1·2
Concrete	20	0·8-1·4
Brick-dry	20	0·38-0·52
Plate glass	20	0·76
Marble	20	2·8
Bakelite	20	0·233
Rubber	20	0·13-0·23
Plexiglass	20	2·184
Celluloid	20	0·215
Beechwood — along grain	20	0·35
Oak — cross grain	20	0·17-0·21
Oak — along grain	—	0·37
Pine — cross grain	20	0·14
Pine — along grain	—	0·26

APPENDIX F

(*Clauses* 6.1.1 *and* C-1.1)

MEASUREMENT OF TEMPERATURE

F-1. GENERAL

F-1.1 It is not the purpose of this appendix to describe the normal instruments used for the temperature measurement of air and liquids, for example, mercury or alcohol thermometers. These and the precautions to be observed in their use are well known and described in the appropriate technical literature.

F-1.2 The same considerations apply to resistance methods (especially platinum resistance thermometers), thermistors and thermocouples mostly used for temperature measurement of solid material. The thermal capacity of the measuring device should be small in comparison with that of the item undergoing test. In addition, the thermal resistance between the measuring device and the item shall be low and the thermal flux led away by the connecting wires has to be kept to a minimum. The power fed to the sensor shall be low enough to avoid undue self-heating of the sensor or heating of the test item.

F-1.3 In the case of heat transfer between a heat dissipating item under test and the walls of the testing chamber, the surface temperature of the materials participating in the thermal exchange are very important. Two methods of surface temperature measurement are available. In one of these, the measuring material makes contact with the surface, the temperature of which is to be measured. In the other, there is no contact between them.

F-1.4 It should be mentioned that, where there is contact with the surface, the surface may become contaminated with a layer of material which is difficult to remove. The use of such methods is, therefore, not permissible in certain cases, for example, in testing of space vehicles.

F-2. METHODS USING COLOUR CHANGING OR MELTING EFFECTS

F-2.0 For many years materials have been used, the colour of which changes with temperature. There are some with a steady colour change within a certain temperature range, as liquid crystals, the attained temperature of which is found by comparison with a colour chart. Other materials change their colour suddenly at certain temperatures when the temperature increases, without reversal of the colour change when the temperature decreases. Such materials are available as colour pencils or special lacquers which can be applied as thin coatings to the surface, the temperature of which is to measured. There are also self-adhesive tapes used as temperature indicators, which change colour when the temperature rises above the predetermined figure for the type which has been used. In other cases, the melting point of a material is used for the measurement.

In all the above examples, where there is a sudden change, it is possible to determine only an overstepping of the temperature at which the change of colour or state occurs, although it is possible to use a number of small samples with differing temperature ranges in order to achieve an assessment of temperature attained.

In general, the accuracy of the measurement, obtainable with all the indicators referred to above, is governed by a number of factors which are referred to below.

F-2.1 In these cases where a change of state at a predetermined temperature is used for temperature indication, it is normally necessary to use a series of indicators with differing sensing temperatures. When one of the indicators changes but the one immediately above it in the series does not, the temperature of the surface lies between the sensing temperatures of the two indicators concerned. The maximum error of measurement will then be equal to the difference between these two sensing temperatures, provided that the predetermined sensing temperature values are not changed by other effects.

F-2.2 Measurement errors of colour changing indicators may be brought about by ageing. When such materials are used for testing over long periods of time at temperatures only slightly below the nominal sensing temperature, there is a risk that the colour change will occur at a lower temperature than that indicated.

F-2.3 The temperature sensing material may also be affected by the presence of liquids, vapours or gases.

F-2.4 Where thermal radiation is falling on the surface of the item, certain precautions shall be taken.

F-2.4.1 When the indicator covers a small portion of a surface which is subjected to radiation, care shall be taken to ensure that the indicator is not heated by the radiation. It is sufficient to shield the indicator by covering it with reflecting material.

F-2.4.2 Where the indicator covers a considerable portion of the surface which is subjected to radiation, the absorption coefficient of the indicator shall not differ appreciably from that of the surface, otherwise the temperature of the surface will be affected by the presence of the indicator.

F-2.5 When using the above methods under conditions of changing temperature, it should be noted that the indication may be low compared with the rate of change of temperature. This results in an underestimation of the actual temperature during the change.

F-3. METHODS USING INFRA-RED SENSORS

F-3.1 An explanation of the essential points of infra-red radiation is given in Appendix C.

F-3.2 In the case of temperature measurement, the emissivity coefficient of the radiating surface shall be known. An infra-red picture received by scanning will be, in fact, a picture of the radiation distribution and not of the temperature distribution. Best results will be achieved by the method of comparison of two small areas at the same temperature, one of which is coated with a material of known emissivity coefficient.

F-3.3 The area covered by the sensor shall be smaller than the surface of which the temperature is to be measured. It may, therefore, be necessary to use an infra-red microscope when the items to be measured are too small for normal radiation detectors. In order to achieve a high accuracy of temperature measurement, it is better to use an instrument picking up radiation emitted from a small area of the item under test.

F-3.4 It should be noted that the area selected shall be sufficiently flat to avoid significant radiation in directions other than that of the sensor. Furthermore, care shall be taken to ensure that radiation from extraneous sources does not reach the sensor directly or by reflection in the measured area.

APPENDIX G

(*Clause* 6.2.1)

MEASUREMENT OF AIR VELOCITY

G-1. Several methods of measurement of air velocity are known, among them the following are relevant.

G-2. One of the oldest instrument is the cup anemometer, mostly used in the meteorological field. The motion of the blown cross-arms can be calibrated in terms of wind speed, that is, air velocity. The available range is very wide and many sizes of cup anemometers are available commercially. By means of a small anemometer, the air velocity can be measured in a small volume, for example, inside a testing chamber.

G-3. The Cata thermometer is a special type of glass thermometer which uses the cooling effect by convection. The principle of measurement is the measurement of time needed for cooling the warmed-up thermometer, for example, from 38 to 35°C. It is usable within the velocity range from approximately 0·05 to 10 $m.s.^{-1}$ and at temperatures from approximately − 10 to + 30°C. However, due to the fact that the thermometer shall be warmed up again after each measurement, this method is cumbersome.

G-4. The cooling effect by convection is also used in the hot-wire anemometer and the thermal anemometer. In both cases, a defined amount of electric power is supplied to the measuring element, thus causing it to reach a predetermined standard temperature. When air flows across the element the temperature of the latter decreases. The magnitude of this decrease in temperature enables the air velocity to be determined. While the hot-wire measuring element consists of a free stretched platinum wire, the measuring element of the thermal anemometer is in many cases a NTC resistor. Because of the available small size and small thermal capacity of such elements, a low thermal time constant can be obtained and a very small cross-section of flow can be measured. It is usable especially for low air velocity and is commercially available for use over a temperature range from approximately − 30 to + 100°C. In the case of the hot-wire anemometer the cooling effect is dependent on the angle between the wire axis and the direction of flow; because the cooling effect is lowest when the airflow is parallel to the wire, the direction of flow can be determined very closely by turning the hot-wire anemometer.

G-5. The methods using cup anemometers and the Cata thermometer are applicable only to large (for example, walk-in) chambers, whilst the methods using a hot-wire or thermal anemometer can be used for small chambers.

G-6. Other methods, suitable for the measurement of air velocity in climatic chambers, are described in the generally available literature.

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